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INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P103523WO	**FOR FURTHER ACTION**	See Form PCT/IPEA/416
International application No. PCT/GB2004/003745	International filing date *(day/month/year)* 01.09.2004	Priority date *(day/month/year)* 01.09.2003
International Patent Classification (IPC) or national classification and IPC G01S1/00, H04B1/707		
Applicant SECRETARY OF STATE FOR DEFENCE DSTL et al		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 6 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 15 sheets, as follows:
      - ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      - ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.

   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the opinion
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☒	Box No. VII	Certain defects in the international application
☐	Box No. VIII	Certain observations on the international application

Date of submission of the demand 01.07.2005	Date of completion of this report 29.12.2005
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Horbach, C Telephone No. +49 89 2399-7928

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

2, 5, 6, 16-31	as originally filed
1, 3, 4, 7-15	received on 08.08.2005 with letter of 03.08.2005

Claims, Numbers

1-30	received on 19.12.2005 with letter of 14.12.2005

Drawings, Sheets

1/14-14/14	as originally filed

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-30
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-30
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-30
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

Box No. VII Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

Reference is made to the following documents:

D1: RIES L ET AL: "A software simulation tool for GNSS2 BOC signals analysis" PROCEEDINGS OF THE INSTITUTE OF NAVIGATION (ION) GPS, XX, XX, 24 September 2002 (2002-09-24), pages 2225-2239, XP002273298

D2: US-B1-6 430 213 (DAFESH PHILIP A) 6 August 2002 (2002-08-06)

D3: US-A-5 729 570 (MAGILL DAVID T) 17 March 1998 (1998-03-17)

D4: BETZ J W: "THE OFFSET CARRIER MODULATION FOR GPS MODERNIZATION" PROCEEDINGS OF THE ION NATIONAL TECHNICAL MEETING, THE INSTITUTE OF NAVIGATION, US, 1999, pages 639-648, XP008025723

D5: RF DESIGN - FUNDAMENTALS OF DIGITAL QUADRATURE MODULATION, vol. 2003, no. February, 1 February 2003 (2003-02-01), pages 40-47, XP002310836 BELLEVUE, NEVADA, USA

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 The subject-matter of Claim 1 complies with the requirements of novelty and inventive step (Articles 33(1-3) PCT) for the following reasons:

1.1 Claim 1 deals with a method of generating a navigation signal comprising a carrier signal, the method comprising the step of multiplying the carrier signal by at least one subcarrier modulation signal.

1.2 Such a method is known from document D1. The subcarrier modulation signals of D1 comprise the rectangular quadrature components of an AltBOC signal. The quadrature components have two possible values.

The very detailed description of the generation of this AltBOC signal results in a "scattered plot" describing the resulting subcarrier modulation signal. This scattered plot resembles a QPSK constellation.

D1 presents another scattered plot resembling an 8PSK signal which describes

another variant of a subcarrier modulation signal; but in contrast to the QPSK scattered plot, the generation of the signal resulting in the 8PSK scattered plot is not included in D1 and it is not possible to extrapolate the detailed description of the QPSK type signal to the 8PSK type signal. Thus, the technical features and implications of this 8PSK type signal are completely unclear. For this reason the teaching of D1 with regard to the 8PSK scattered plot is not enabling and consequently it is not relevant to the novelty of claim 1 (PCT Guidelines of 2004 paragraph 12.02).

1.3 Thus, claim 1 differs from the disclosure of D1 by further defining that the at least one subcarrier modulation signal comprises a number, m, of discrete amplitude levels derived from or associated with an m-ary phase constellation, where m>2.

Consequently, the subject-matter of claim 1 is new (Article 33(2) PCT).

1.4 Using more than two amplitude levels allows for controlling the emissions of the sidebands of the spectrum of the AltBOC signal, which is not possible if only two amplitude levels are used.
Thus, the problem consists of improving the spectral properties of the ranging signal using subcarrier modulation.

1.5 The skilled person finds in D1 the 8PSK scattered plot; however this scattered plot would not direct the skilled person to the solution of claim 1: as the complete document D1 only deals with binary valued subcarriers, the skilled person would not have considered to form a signal having more than 2 discrete amplitude values. Thus, the skilled person would not have arrived at a method according to claim 1 without involvement of an inventive step (Article 33(3) PCT).

1.6 Documents D2 and D4 deal with ranging signals address the problem but they do not provide a teaching how to use more than 2 amplitude levels for the modulation of the subcarriers. Instead all these documents deal with binary phase modulation and either sinusoidal signals or binary-valued signals.

Documents D3 and D5 do not deal with ranging signals.

2 The navigation signal of independent claim 20 complies with the requirements of novelty and inventive step (Articles 33(1-3) PCT) for the same reasons as claim 1, because its characteristics are defined by the same formulations as found in claim 1.

3 Claims 2-19 and 21-27 are dependent claims on claims 1 and 20 respectively. Thus, these claims comply with the requirements of novelty and inventive step (Articles 33(1-3) PCT) for the same reasons as claim 1.

4 Claims 28-30 are independent claims being directed to a system, a receiver system and a computer readable medium, respectively. But by their reference to the preceding claims their features are defined by the same characteristics as claim 1. Thus, these claims comply with the requirements of novelty and inventive step (Articles 33(1-3) PCT) for the same reasons as claim 1.

Re Item VII

Certain defects in the international application

5 The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

6 In order to meet the requirements of Rule 5.1(a)(ii) of the PCT, the document D1 cited above should be acknowledged and briefly discussed in the opening part of the description.

MODULATION SIGNALS, SYSTEM AND METHOD

Field of the Invention

The invention relates to modulation signals, systems and methods such as, for example, navigation and positioning signals, systems and methods.

Background to the invention

Satellite Positioning Systems (SPS) rely on the passive measurement of ranging signals broadcast by a number of satellites, or ground-based or airborne equivalents, in a specific constellation or group of constellations. An on-board clock is used to generate a regular and usually continual series of events, often known as 'epochs', whose time of occurrence is coded into a random or pseudo-random code (known as a spreading code). As a consequence of the pseudo-random or random features of the time epoch encoding sequence, the spectrum of the output signal is spread over a frequency range determined by a number of factors including the rate of change of the spreading code elements and the waveform used for the spreading signal. Typically, the spreading waveform is rectangular and has a sinc function power spectrum.

The ranging signals are modulated onto a carrier signal for transmission to passive receivers. Applications are known that cover land, airborne, marine and space use. Typically, binary phase shift keying is employed to modulate the carrier signal, which, itself, has a constant magnitude. Usually, at least two such signals are modulated onto the same carrier in phase quadrature. The resulting carrier signal retains its constant envelope but has four phase states depending upon the two independent input signals. However, it will be appreciated that two modulating signals do not need to have the same carrier magnitude. It is possible for a constant carrier magnitude of the combined signal to be maintained by appropriate selection of corresponding phases other than $\pi/2$ radians.

An example of such a satellite positioning system is the Global Positioning System (GPS). Generally, the GPS operates using a number of frequencies such as, for example, L1, L2 and L5, which are centred at 1575.42 MHz, 1227.6 MHz and 1176.45 MHz respectively. Each of these signals is modulated by respective spreading signals. As will be appreciated by those skilled in the art, a Coarse Acquisition (CA) code signal emitted by the GPS Satellite Navigation System is broadcast on the L1 frequency of 1575.42MHz with a spreading code rate (chip rate) of 1.023MHz. The CA has a rectangular spreading waveform and is categorised as BPSK-R1. The GPS signal structure is such that the signal broadcast by the satellites on the L1 frequency has a second component in phase quadrature, which is known as the precision code (P(Y) code) and is made available to authorised users only. The P(Y) signal is BPSK modulated with a spreading code at 10.23MHz with a magnitude which is 3dB lower in signal power than the CA code transmission. Consequently, the Q component

spectrum 104 for the P(Y) code has a maximum amplitude centred on the L1 and L2 frequencies, with zeros occurring at multiples of ±10.23MHz as is expected with a sinc function waveform.

It is known to further modulate the ranging codes using a sub-carrier, that is, a further signal is convolved with the P codes and/or CA codes to create Binary Offset Carrier (BOC) modulation as is known within the art see, for example, J. W. Betz, "*Binary Offset Carrier Modulation for Radionavigation*", Navigation, Vol. 48, pp227-246, Winter 2001-2002. Standard BOC modulation 200 is illustrated in figure 2. Figure 2 illustrates the combination of a portion of a CA code 202 with a subcarrier signal to produce the BOC signal 204 used to modulate a carrier such as, for example, L1. It can be appreciated that the BOC signal is a rectangular square wave and can be represented as, for example, $c_i(t)*\mathrm{sign}(\sin(2\pi f_s t))$, where f_s is the frequency of the subcarrier. One skilled in the art understands that $BOC(f_s,f_c)$ denotes Binary Offset Carrier modulation with a subcarrier frequency of f_s and a code rate (or chipping rate) of f_c. Using binary offset carriers results in the following signal descriptions of the signals emitted from the satellite:

$$S_{L1i}(t) = A_m sc_{im}(t)m_i(t)d_i(t)\cos(\omega_1 t) + A_C sc_{ig}(t)g_i(t)d_i(t)\sin(\omega_1 t) = I_{SL1i}(t) + Q_{SL1i}(t)\text{, and}$$

$$S_{L2i}(t) = B_m sc_{im}(t)m_i(t)d_i(t)\cos(\omega_2 t)$$

where

A_m, A_c and B_m are amplitudes;

$m_i(t)$ is an m-code BOC(10,5) signal;

$g_i(t)$ is a Galileo open service range code;

$sc_{im}(t)$ represents the sub-carrier signal for $m_i(t)$;

$sc_{ig}(t)$ represents a subcarrier signal for $c_i(t)$;

ω_1 and ω_2 are the L1 and L2 carrier frequencies;

Figure 2 also illustrates power spectra for a BPSK-R1 code and pair of BOC signals, that is, BOC(2,1) and BOC(10,5). The first spectrum 202 corresponds to BPSK-R1 code. The second power spectrum 204 corresponds to the BOC(2,1) code and the third power spectrum 206 corresponds to the BOC(10,5) code. It can be appreciated that the side lobes 208 of the BOC(2,1) signal have relatively large magnitudes. Similarly, the illustrated side lobe 210 of the BOC(10,5) signal has a relatively large magnitude. One skilled in the art appreciates that the energy in the side lobes are a source of interference.

It is an object of embodiments of the present invention to at least mitigate the problems of the prior art.

Summary of Invention

Accordingly, a first aspect of embodiments of the present invention provides a method as claimed in claim 1.

A second aspect of embodiments of the present invention provides a signal as claimed in claim 20.

A third aspect of embodiments of the present invention provides a system as claimed in claim 28.

A fourth aspect of embodiments of the present invention provides a received as claimed in claim 29.

A fifth aspect of embodiments provides a computer readable storage as claimed in claim 30.

Advantageously, embodiments of the present invention provide significantly more control over the shape of the power spectra of signals, that is, the distribution of energy within those signals.

Other aspects of the present invention are described and defined in the claims.

Brief Description of the Invention

Embodiments of the present invention will now be described, by way of example, only with reference to the accompanying drawings in which:

figure 1 shows a power spectrum of a pair of ranging code;

figure 2 illustrates power spectra of a ranging code (BPSK-R1) and BOC(10,5) signals;

figure 3 illustrates a multi-level sub-carrier;

figure 4 illustrates the phase states for at least a pair of multilevel subcarriers according to embodiments of the present invention;

example, a BOC8(2,2) signal exhibits a 10-12 dB improvement in spectral isolation as compared to a conventional BOC(2,2) signal. Further information on the relationship between SSC and signals according to embodiments of the present invention can be found in, for example, Pratt & Owen; BOC Modulation Waveforms, IoN Proceedings, GPS 2003 Conference, Portland, September 2003, which is incorporated herein by reference for all purposes and filed herewith as in the appendix.

Furthermore, embodiments of the present invention utilise the magnitude and duration of the subcarrier to influence, that is, control the energy in harmonics of the resulting modulating waveform. For example, referring still to figure 5, it can be appreciated that additional spectral nulls appear in the BOC8(2,2) spectrum at substantially 6MHz and 10MHz offset from the carrier whereas there are no such nulls in the conventional BOC(2,2) signal. The location of the nulls is influenced by at least one of the magnitude and duration of the steps in the multilevel subcarrier. More specifically, the nulls can be steered to desired locations by changing either of these two elements, that is, the position of the nulls is influenced by these two elements. Appendix A contains an indication of the relationship between the spectra of signals according to embodiments of the present invention and the magnitude and duration of the steps.

Referring to figure 6, there is shown subcarrier states or amplitudes for I and Q signals for a further BOC8 signal, that is, a binary offset carrier having eight states. It can be appreciated that the eight states can be represented by, or correspond to, subcarrier amplitudes chosen from the set $(-\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2)$ ie four states or signal amplitudes rather than the five states or signal amplitudes described above. Therefore, the I and Q components are constructed from the following signal elements such that $\sqrt{(\cos^2 \vartheta + \sin^2 \vartheta)} = 1$, that is, $\pm\sqrt{3}/2$ can only occur in conjunction with $\pm 1/2$, are as follows:

I phase - $(+1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2)$ representing a +1 chip of a ranging code signal

I phase - $(-1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2)$ representing a -1 chip of a ranging code signal

Q phase - $(+\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2)$ representing a +1 chip of a ranging code signal

Q phase - $(-\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2,)$ representing a -1 chip of a ranging code signal.

It will be appreciated that the states 1 to 8 shown in figure 6 are not equidistantly disposed circumferentially. The transitions between states 2&3, 4&5, 6&7, 8&1 are larger in angular step than the transitions between states 1&2, 3&4, 5&6, 7&8. It will be appreciated that when these states are translated into subcarrier amplitudes, the duration of a given amplitude will depend on the duration or dwell time of a corresponding state, that is, the durations for which the subcarrier remains in any

given state may no longer be equal unlike the states of figure 4 above. The dwell times are a matter of design choice such as, for example, to minimise the mean square difference between a stepped waveform and a sinusoid. Figure 7a illustrates the subcarriers 700 and 702 corresponding to the states shown in figure 6. It can be appreciated that the durations of or within each state of the subcarriers 700 and 702 are equal. The Q channel subcarrier magnitudes will follow substantially the same pattern as described above but phase shifted by $\pi/2$ radians. The subcarrier 702 for the Q channel is shown in dotted form in figure 7. It will be appreciated that such subcarriers provide a constant envelope magnitude since $(I^2+Q^2)^{1/2}=1$ for all amplitude combinations. However, referring to figure 7b, there is shown a pair of subcarriers 704 and 706 in which the durations at each state are unequal. It will be appreciated that not all amplitude combinations satisfy $(I^2+Q^2)^{1/2}=1$. Therefore, the transmitted signal will not have a constant envelope.

It will be appreciated by those skilled in the art that a stepped half cycle of the subcarrier corresponds to one chip. However, other embodiments can be realised in which other multiples of half cycles correspond to a chip. For example, embodiments can be realised in which two half cycles of a subcarrier correspond to a chip. In such embodiments the signals for the I and Q channels would be

I phase - $(+1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2)$ representing a +1 signal

I phase - $(-1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2)$ representing a -1 signal

Q phase - $(+\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2)$ representing a +1 signal

Q phase - $(-\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2)$ representing a -1 signal.

Similarly, embodiments realised using three half cycles per chip would produce

I phase - $(+1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2)$ representing a +1 signal

I phase - $(-1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2)$ representing a -1 signal

Q phase - $(+\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2)$ representing a +1 signal

Q phase - $(-\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2, +\sqrt{3}/2, +1/2, -1/2, -\sqrt{3}/2, -\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2)$ representing a -1 signal.

One skilled in the art will appreciate that the above can be extended to n half cycles of a subcarrier per ranging code chip.

It will be appreciated that other phases can be used to describe the subcarriers. For example, phase and amplitude components of 16-PSK can be used to create BOC16 subcarriers having 9 levels, assuming that the first state is at (+1,0). Using m-PSK phase states can be used to produce (m+2)/2

level subcarrier signals. Therefore, setting m=2 gives the conventional BPSK and a two-level subcarrier. Setting m=4 provides a 3 level subcarrier, that is, BOC4 modulation, setting m=8 produces a 5 level subcarrier, that is, BOC8 modulation, setting m=16 produces a 9 level subcarrier, which corresponds to BOC16 modulation.

It will be appreciated that several further variations in the assignment of code and data states to the phase locations can be realised. For example, rotation of the states shown in figure 4 by 22.5° leads to a reassignment of angles associated with the states from the angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) to the angles (22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5°, 337.5°). Again, it will be appreciated that this does not cause a change in the modulus of the spectrum and, again, the required number of amplitude levels reduces from 5 to 4, that is, m-PSK can be used to realise [(m+2)/2-1] amplitudes according to appropriate rotation and alignment of the phase states. The resulting waveforms for the I and Q components are built, in this case, from the following signal element sequences:

I phase - (+cos(67.5°), +cos(22.5°), +cos(22.5°), +cos(67.5°)) representing a +1 signal

I phase - (-cos(67.5°), -cos(22.5°), -cos(22.5°), -cos(67.5°)) representing a -1 signal

Q phase - (+sin(67.5°), +sin(22.5°), -sin(22.5°), -sin(67.5°)) representing a +1 signal

Q phase - (-sin(67.5°), -sin(22.5°), +sin(22.5°), +sin(67.5°)) representing a -1 signal.

It should be noted that the I and Q signal element sequences for the cases described above are orthogonal over the duration of one spreading pulse (chip). Clearly, other rotations are possible and will yield orthogonal signal element sets.

An alternative way of representing the above is via a state table. Assume that an embodiment of a BOC8 modulation has been realised with equidistant states and the first state has a phase angle of $\pi/8$ radians (22.5°) as shown in figure 8, which corresponds to the above values. The sequence of phase states required for each I and Q ranging code signal component, assuming that the ranging codes transition substantially simultaneously and a desire to maintain a substantially constant output envelope, that is, the states for the subcarriers would be given by

I	Q	t1	t2	t3	t4
+1	+1	2	1	8	7
-1	+1	3	4	5	6
+1	-1	7	8	1	2
-1	-1	6	5	4	3

Table 1 – Sequence of States for BOC8(x,x) I & Q signal elements

It will be appreciated that the subcarrier corresponding to the phase states in Table 1 comprises a half cycle per ranging code chip. Furthermore, the sense of the phasor is clockwise when I and Q are equal and anticlockwise otherwise. It will be apparent that the signal element sequences or state sequences are sections (specifically half cycle sections in the aspect of the invention disclosed above) of a sampled or quantised sinusoid. The concept can, therefore, be extended to include a multiplicity of such samples. Those variants, which appear to be useful, include the cases with samples from a finite number of half cycles, that is, rather than, for example, an I channel value of +1 being represented by the states of 2, 1, 8 and 7, it can be represented using some other number of states such as, for example, 2, 1, 8, 7, 6, 5, 4, 3, 2, 1, 8, 7 ie by three half cycles of the sample or quantised sinusoid. Table 2 illustrates the phase states for such an embodiment and is based on the phase state diagram of figure 4 for samples but using three half cycles (or an arbitrary number of half cycles) of the sinusoid waveform. The sinusoid or portion or multiple of half cycles thereof is known as the 'basis waveform'. One skilled in the art realises that other basis waveforms can be used such as, for example, a triangular waveform or a set of mutually orthogonal waveforms.

I	Q	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12
+1	+1	2	1	8	7	6	5	4	3	2	1	8	7
-1	+1	3	4	5	6	7	8	1	2	3	4	5	6
+1	-1	7	8	1	2	3	4	5	6	7	8	1	2
-1	-1	6	5	4	3	2	1	8	7	6	5	4	3

Table 2 – Sequence of States for 8-PSK I & Q Signal Elements with 1½ cycles of sub-carrier per chip modulation

I	Q	t1	t2	t3	t4	t5	t6	t7	t8
+1	+1	2	1	8	7	6	5	4	3
-1	+1	3	4	5	6	7	8	1	2
+1	-1	7	8	1	2	3	4	5	6
-1	-1	6	5	4	3	2	1	8	7

Table 3 – Sequence of States for 8-PSK I & Q Signal Elements with two half cycles of sub-carrier per chip modulation.

One skilled in the art will appreciated that it is assumed in Tables 1 to 3, that the I and Q chip transitions happen substantially simultaneously and, furthermore, that the I and Q subcarriers take the form of sine and cosine waveforms respectively. However, embodiments can be realised in which the ranging code chip transitions do not occur substantially simultaneously. Furthermore, in circumstances in which the ranging code chip transitions do not occur substantially simultaneously, the subcarriers corresponding to the I and Q ranging code chips can be arranged to take the form of a pair of quantised sine waves.

It will seen that there are 4 time samples for each ½ cycle of the waveform. The stepped sinusoidal waveform may be viewed as sub-carrier modulation of the basic spreading waveform. The number of time samples and independent information bearing channels is related to the number of phase states, which the carrier signal has in its representation. Although the examples above have used phase states that are 'powers of 2', embodiments can be realised in which some other number is used. For example, a 6-PSK carrier signal can be used to carry 2 independent information bearing binary channels. In this case only 3 signal element samples are required per transmitted code chip.

One skilled in the art appreciates that the replacement of the stepped sinusoid with a rectangular wave with the duration of each element being equal to a ½ cycle of the sinusoid is well known within the art. As indicated above, it is known as 'Binary Offset Carrier' modulation. There are usually 2 further attributes associated with the BOC description, which relate to the frequency of the code chipping rate

and to the frequency of the offset sub-carrier. BOC(2,2) consequently is interpreted as a waveform with a 2.046MHz chipping rate and a 2.046MHz offset sub-carrier. This arrangement has exactly two ½ cycles of the sub-carrier signal for each code element (chip).

A further aspect of embodiments of the present invention relates to using a set of subcarriers to modulate ranging codes, with at least one or more, or all, of the subcarriers being multilevel waveforms. One skilled in the art may think of such embodiments as modulation of the subcarrier signal by a further subcarrier signal. The resulting signal transmitted by an ith satellite or system having a carrier frequency of ω_i, for an additional subcarrier, would have the form:

$$S_i(t) = A_m sc_{jm}(t) sc_{im}(t) m_i(t) d_i(t)\cos(\omega_i t) + A_C sc_{jg}(t) sc_{ig}(t) g_i(t) d_i(t)\sin(\omega_i t) = I_{Si}(t) + Q_{Si}(t)$$

where

$sc_{im}(t)$ and $sc_{jm}(t)$ represent first and second subcarrier signals respectively first ranging codes such as, for example, M-codes; and

$sc_{ig}(t)$ and $sc_{jg}(t)$ represent first and second subcarrier signal second ranging codes such as, for example, Gold codes.

It should be noted that embodiments can be realised in which $sc_{im}(t)$ and $sc_{ig}(t)$ are the same or different. Similarly, embodiments can be realised in which $sc_{jm}(t)$ and $sc_{ig}(t)$ are the same or different.

$$S_i(t) = A_m \prod_{j=1}^{n} sc_{ijm}(t) m_i(t) d_i(t)\cos(\omega_i t) + A_C \prod_{j=1}^{l} sc_{ijg}(t) g_i(t) d_i(t)\sin(\omega_i t) = I_{Si}(t) + Q_{Si}(t),$$

where $\prod_{j=1}^{n} sc_{ijm}(t)$ *and* $\prod_{j=1}^{l} sc_{ijg}(t)$ represents the product of the subcarriers for the first and second ranging codes such as, for example, the m and Gold codes.

Although it is possible to use more than one subcarrier, practical embodiments will typically use 2 subcarriers. Modulation using a pair of subcarriers is known as Double Binary Offset Carrier (DBOC) modulation. Modulation using three subcarriers is known as Triple Binary Offset Carrier (TBOC) modulation and so on such that modulation using a n-tuple of subcarriers is known as N-tuple Binary Offset Carrier (NBOC). As mentioned above, one or more than one of the subcarriers may be stepped, that is, having magnitudes related to respective phase states.

As examples of this aspect of the invention, figure 9 illustrates a pair of waveforms 900. In figure 9, as an illustration of the NBOC invention, the subcarrier basis waveforms are assumed to be binary and only a single subcarrier waveform 902 is shown. The time duration in figure 9 is 512 samples and

exactly matches the duration of one code element duration (chip). The first subcarrier 902 contains 4 half cycles of a subcarrier per ranging code chip, as illustrated by the dashed waveform. If this was the only sub-carrier component, the modulation would be a BOC(2x,x) type, where x is the frequency of the code rate (chipping rate). However, it can be appreciated that a second sub-carrier (not shown) having 16 half cycles per 512 samples has been used to produce the modulated waveform 904 to be combined with the carrier of the satellite signal. The modulated waveform is shown by the solid curve. As a result of modulation (multiplication) of the two subcarriers, the resulting waveform 904 has phase reversals for the second subcarrier 904 whenever there is a sign reversal in the first subcarrier 902. This is clearly evident in figure 9 at points 906, 908 and 910, where the transitions of the second subcarrier (not shown) would have been opposite. The resulting modulation is denoted Double BOC, or DBOC. In the case of figure 9, the modulation is DBOC(8x,(2x,x)), that is, there are 8 half cycles of the second subcarrier per chip of the ranging code (not shown). The main energy is concentrated around frequencies ±8x from the carrier signal, with a BOC-like double humped spectrum.

Referring to figure 10, there is shown a pair of power spectra 1000. A first power spectrum 1002 relates to a DBOC8(16,(2,2)) signal. It will be appreciated that at least one of the first and second subcarriers used to create the DBOC8(16,(2,2)) signal comprised amplitudes derived from 8 corresponding phase states. In the specific embodiment shown, the first subcarrier was the multi-level signal. It will be appreciated that the nomenclature for representing DBOC modulation or subcarriers is DBOCa(b,c(d,e)), where a and c represent the number of phase states, that is, amplitudes, of the subcarriers having frequencies b and d respectively. The second spectrum 1004 relates to a BOC8(2,2) signal. The spectra shown have been made using a previous aspect of the invention, that is the use of multilevel subcarriers or subcarriers having more than two phase states, in combination with the Double BOC concept. The waveforms for I & Q modulations for the spectrum of figure 10 are shown in figure 11. Referring to figure 11 there is shown a pair 1100 of waveforms. The first pair of waveforms 1102, representing the I channel of the spreading waveform, comprises a stepped or multi-level BOC(2,2) signal 1104, represented by the solid line, and a 16Mhz subcarrier modulated BOC(2,2) signal 1106, represented by the dashed line. It will be appreciated that the 16 MHz subcarrier modulated BOC(2,2) signal has been produced by multiplying the BOC8(2,2), that is, stepped BOC(2,2) signal, by a 16 MHz rectangular waveform (not shown) having amplitudes of ± 1. The second waveform 1108, representing the Q channel, comprises a quadrature BOC(2,2) signal 1110 together with a 16MHz subcarrier modulated BOC(2,2) signal 1112. It can be appreciated that the first subcarrier 1104 or 1110 is a subcarrier according to an embodiment of the present invention described above whereas the second sub-carrier (not shown) in both cases are conventional binary rectangular waveforms, that is, conventional subcarriers. It can be appreciated that there are regions 1114 of overlap between the two BOC(2,2) subcarriers 1104 and 1110 and their resulting products,

that is, 16 MHz subcarrier modulated BOC(2,2) signals 1106 and 1112. In the regions of overlap 1114, the waveforms have the same amplitude profile.

An advantage of the embodiments of the signals shown in figure 11 is that the I channel or component has been produced or represents DBOC8 modulation or signal whereas the Q channel has been produced using or represents BOC8 modulation. However, this arrangement still preserves or provides a substantially constant envelope carrier signal to be emitted from the satellite.

Embodiments of the present invention have been described with reference to the subcarrier signals being periodic. However, embodiments can be realised in which the subcarrier signal comprises a pseudorandom noise signal. Furthermore, embodiments can be realised in which the shape of the subcarrier takes a form other than a stepped, that is, a multilevel wave or quantised approximation of a sinusoidal waveform. For example, multilevel-pulsed waveforms, multilevel-periodic waveforms or multilevel-aperiodic waveforms, could be used such as the signal shown in figure 12 according to the influence one skilled in the art wishes the resulting modulation to have on the power spectrum of the transmitted signal and/or any appropriate measure of interference such as, for example, SSC or self-SSCs.

Referring to figure 13, there is shown a subcarrier waveform 1300 according to a further embodiment of the present invention together with one chip 1302 of a code or other waveform such as, for example, another subcarrier. It can be appreciated that the subcarrier comprises a first portion of a BOC(5,1) waveform, in the 100 ns sections, combined with portions of a BOC(1,1) waveform, in the 400 ns portions, to produce an overall subcarrier. It will be appreciated that the spectra of the BOC(5,1) waveform will have a peak at 5*1.023MHz and the BOC(1,1) waveform will have a peak at 1*1.023MHz. Therefore, one skilled in the art appreciates that selectively combining the BOC subcarriers allows one skilled in the art to position or relocate the peaks of the overall subcarrier. Again, it can be appreciated that the subcarrier used, for example, to modulate the ranging codes is derived from more than one subcarrier. Although the signal described in relation to figure 13 has been derived from BOC(5,1) and BOC(1,1) subcarriers, embodiments can be realised in which other combinations of BOC subcarriers are used. In effect, the BOC(5,1) and BOC(1,1) signals have been multiplexed or selectively combined to produce an overall subcarrier signal. It will be appreciated that other sequences for the subcarriers can be realised according to a desired effect upon the power spectrum of a transmitted signal. For example, a subcarrier can be realised using a pseudorandom sequence as a sub-carrier instead of the stepped modulations. The use of additional sequences to that of the main spreading code has hitherto been limited to use as a tiered code, which changes state after every complete code repetition interval. The GPS L5 codes are constructed in this manner using Neumann Hoffman sequences of length 10 or 20 to extend a 1ms code (of 10230 chips or elements) to 10ms or 20ms. The use of a subcode chip interval has not previously been considered. A complete

sequence (a sub-sequence) has a duration of one code chip, or at most a plurality, of code chips. It fulfills a similar role to the sub-carrier modulation as previously described in that it controls the spectrum of the emissions. One feature of such a sub-sequence is that such sequences may be chosen to be common amongst a satellite constellation or a sub-set of the constellation. One such subset might be a group of ground transmitters providing a local element or augmentation to the space segment of the system. For example, subcarrier amplitudes can be realised that have the sequence -++++----+ in 10 subchip intervals or other sequence of +1's and −1's per ranging code chip or other subcarrier chip according to the desired effect on spectrum of the resulting signal. Examples such as the 7 subchip interval sequences would include ++-----, +++----, +-+-+--, and can be chosen to provide similar control over the emitted spectrum.

Referring to figure 14, there is shown, schematically, a transmitter 1400 according to an embodiment of the present invention. The transmitter 1400 comprises means 1402, that is, a generator, for generating or selecting the ranging codes for transmission. It will be appreciated by those skilled in the art that such ranging codes may be generated by, for example, shift register implementations. It can be appreciated that the ranging code selection and/or generation means 1402 is illustrated as producing $g_i(t)$ and $m_i(t)$. These codes are fed to respective mixers 1404 and 1406. The mixers 1404 and 1406 are arranged to combine the ranging codes with subcarriers according to embodiments of the present invention. Respective subcarrier generators 1408 and 1410 generate the subcarriers. Optionally, a data signal, $d_i(t)$, is also preferably mixed with the ranging codes and subcarriers. The duration of one bit of the data signal is normally an integer multiple of the code repetition interval. For example, in GPS CA code, it is 20 times the 1 ms code repetition interval, that is, the data rate is 50 bps. The mixed signals 1412 and 1414 are fed to a further pair of mixers 1416 and 1418, where they are mixed with in-phase and quadrature phase signals produced via an oscillator and phase shifter assembly 1420. The further mixed signals 1422 and 1424 are combined, via a combiner 1426, and output for subsequent up conversion by an appropriate up converter 1428. The output from the up converter 1428 is fed to a high-power amplifier 1430 and then filtered by an appropriate filter 1433 for subsequent transmission by, for example, a satellite or other device arranged to emit or transmit the ranging codes.

Referring to figure 15, there is shown a schematic representation of a modulation system 1500 according to an embodiment. The system 1500 comprises a ranging code generator 1502 for producing a ranging code. The ranging code is fed to a first lookup table 1504 comprising phase states and a second lookup table 1506 comprising amplitude states. The output of the phase state lookup table 1504 is used to drive a phase modulator 1508, which, in turn, produces a voltage signal to control the phase of a voltage controlled oscillator 1510. The output of the oscillator 1510 is combined, via, a combiner 1512 such as, for example, a gain controlled amplifier or multiplier, with a

CLAIMS

1. A method of generating a navigation signal comprising a carrier signal, the method comprising the step of multiplying the carrier signal by at least one subscarrier modulation signal; wherein the at least one subcarrier modulation signal comprises a number, m, of discrete amplitude levels derived from or associated with an m-ary phase constellation, where $m > 2$.

2. A method as claimed in claim 1 in which m is selected from at least one of 3, 4, 5, 6, 7, 8 or 9.

3. A method as claimed in any preceding claim in which the at least one subcarrier modulation signal approximates or is derived from a basis waveform.

4. A method as claimed in claim 3 in which the basis waveform is at least one of a sine wave, cosine wave, or triangular waveform.

5. A method as claimed in either of claims 3 and 4 in which the basis waveform is selected according to desired power distribution characteristics of the transmission signal.

6. A method as claimed in any preceding claim in which the at least one subcarrier comprises at least two mutually orthogonal subcarrier modulation signals.

7. A method as claimed in claim 6 in which the at least two subcarriers comprises a pair of subcarriers having a predetermined phase relationship.

8. A method as claimed in any preceding claim in which the at least one subcarrier comprises an in-phase subcarrier and a quadrature phase subcarrier.

9. A method as claimed in claim 8 further comprising the step of determining the respective multiple amplitudes of the in-phase and quadrature phase subcarriers to maintain a substantially constant transmission signal envelope.

10. A method as claimed in any preceding claim further comprising the steps of deriving amplitudes associated with the at least one subcarrier from a plurality of phase states.

11. A method as claimed in claim 10, in which the phase states are equally angularly distributed around a unit circle.

12. A method as claimed in any preceding claim in which durations of the amplitudes of the at least one subcarrier are equal.

13. A method as claimed in any preceding claim in which durations of at least a pair of amplitudes of the at least one subcarrier are different.

14. A method as claimed in any of claims 12 to 13 in which the durations are quantised according to an associated clock signal.

15. A method as claimed in any preceding claim in which at least a pair of subcarriers cooperate to define an associated plurality of phase states resolved according to mutually orthogonal axes.

16. A method as claimed in claim 15 in which the plurality of phase states is associated with respective ranging signals.

17. A method as claimed in either of claims 15 and 16, in which dwell times in at least some of the plurality of phase states are unequal.

18. A method as claimed in any of claims 15 to 17 in which a first group of the phase states have a first dwell and a second group of the phase states have a second dwell time.

19. A method as claimed in any of claims 15 to 18 in which the dwell times are quantised according to a clock.

20. An m-level navigation subcarrier modulation signal for modulating a signal; the m-level subcarrier modulation signal comprising discrete signal amplitudes derived from or associated with an m-ary phase constellation, where $m>2$.

21. A signal as claimed in claim 20, wherein the plurality of signal amplitudes are associated with, or derived from, a plurality of phase states associated at least the m-level subcarrier modulation signal and a second signal.

22. A signal as claimed in claim 21 in which the second signal has a predetermined phase relationship with the m-level subcarrier modulation signal.

23. A signal as claimed in claim 22 in which the predetermined phase relationship is a quadrature phase relationship.

24. A signal as claimed in any of claims 20 to 23 in which the m signal amplitudes comprises amplitudes representing a quantised sinusoidal signal.

25. A signal as claimed in any of claims 20 to 24 in which the m signal amplitudes are, or are in proportion to, at least one of the following sets of amplitudes $\{+1, +1/\sqrt{2}, 0, -1/\sqrt{2}, -1\}$,

$\{-\sqrt{3}/2, -1/2, +1/2, +\sqrt{3}/2\}$, $\{(\pm\sin(67.5°), \pm\sin(22.5°), \pm\sin(22.5°), \pm\sin(67.5°)\}$, $\{\pm\cos(67.5°), \pm\cos(22.5°), \pm\cos(22.5°), \pm\cos(67.5°)\}$.

26. A signal as claimed in claim 25 wherein the signal amplitudes are selected to achieve a predetermined magnitude characteristic in a transmitted signal.

27. A signal as claimed in claim 26 in which the predetermined magnitude characteristic is a constant envelope of the transmitted signal.

28. A system comprising means to implement a method or generate a signal as claimed in any preceding claim.

29. A receiver system comprising means to process a signal as claimed in any of claims 20 to 27.

30. Computer readable storage comprising computer executable code for implementing or producing a method, signal or system as claimed in any preceding claim.